Estimating Impacts of Land Use upon Groundwater Quality Using the Trilinear Analysis Technique

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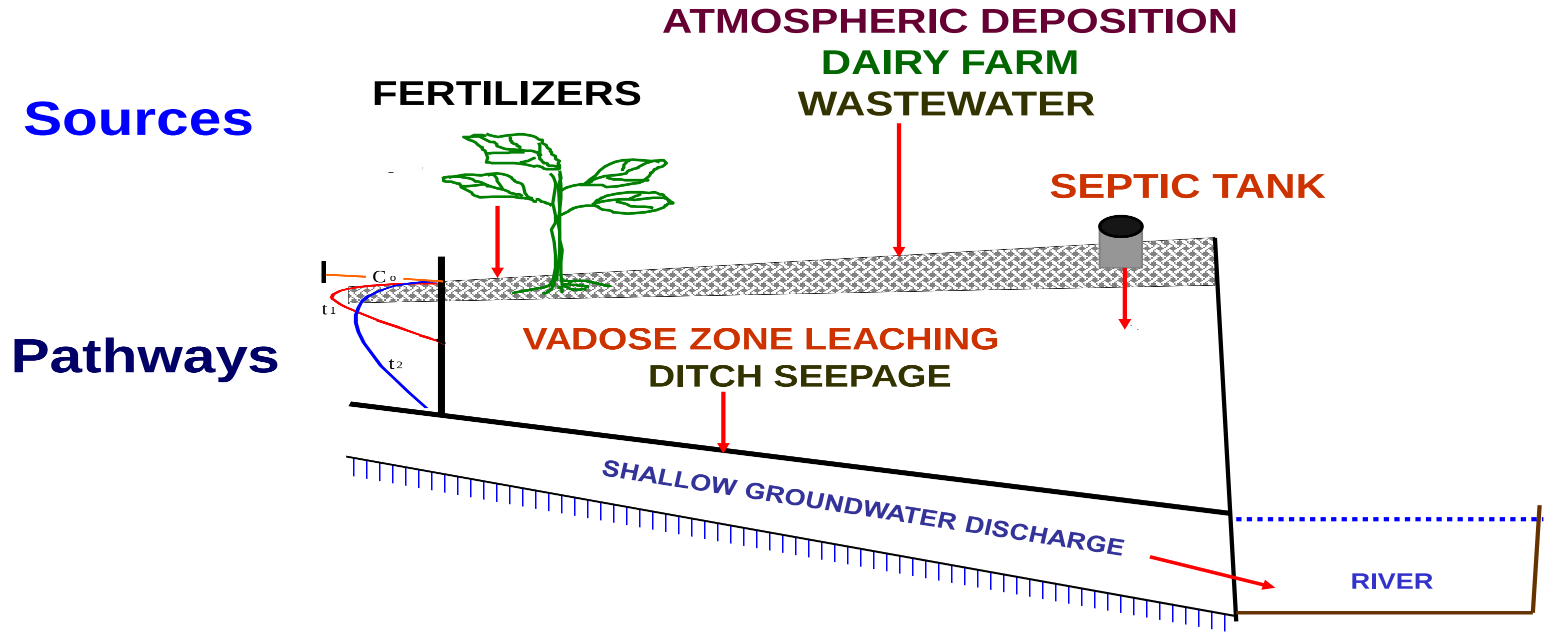

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Rationale

- Groundwater is connected to the landscape above

- Land use changes may affected groundwater quality

Objectives

- Overview of trilinear analysis
- Procedures on application of trilinear analysis
- Example Application --- Impacts of agricultural, septic tank, forest, and wastewater land uses on nutrient, cation, anion, and heavy metal in groundwater

What is Trilinear Analysis?

- A display of experimental data in a triangular graph
- Data should contain three components, each of which can be expressed as a percentage of the total of the three
- The sum of the three percentage components should be equal to 100% (Piper, 1953)

What is Trilinear Analysis (continued)?

The data from the three percentage components are converted to X-Y coordinates using the following equations (Shikaze and Crowe, 2007)

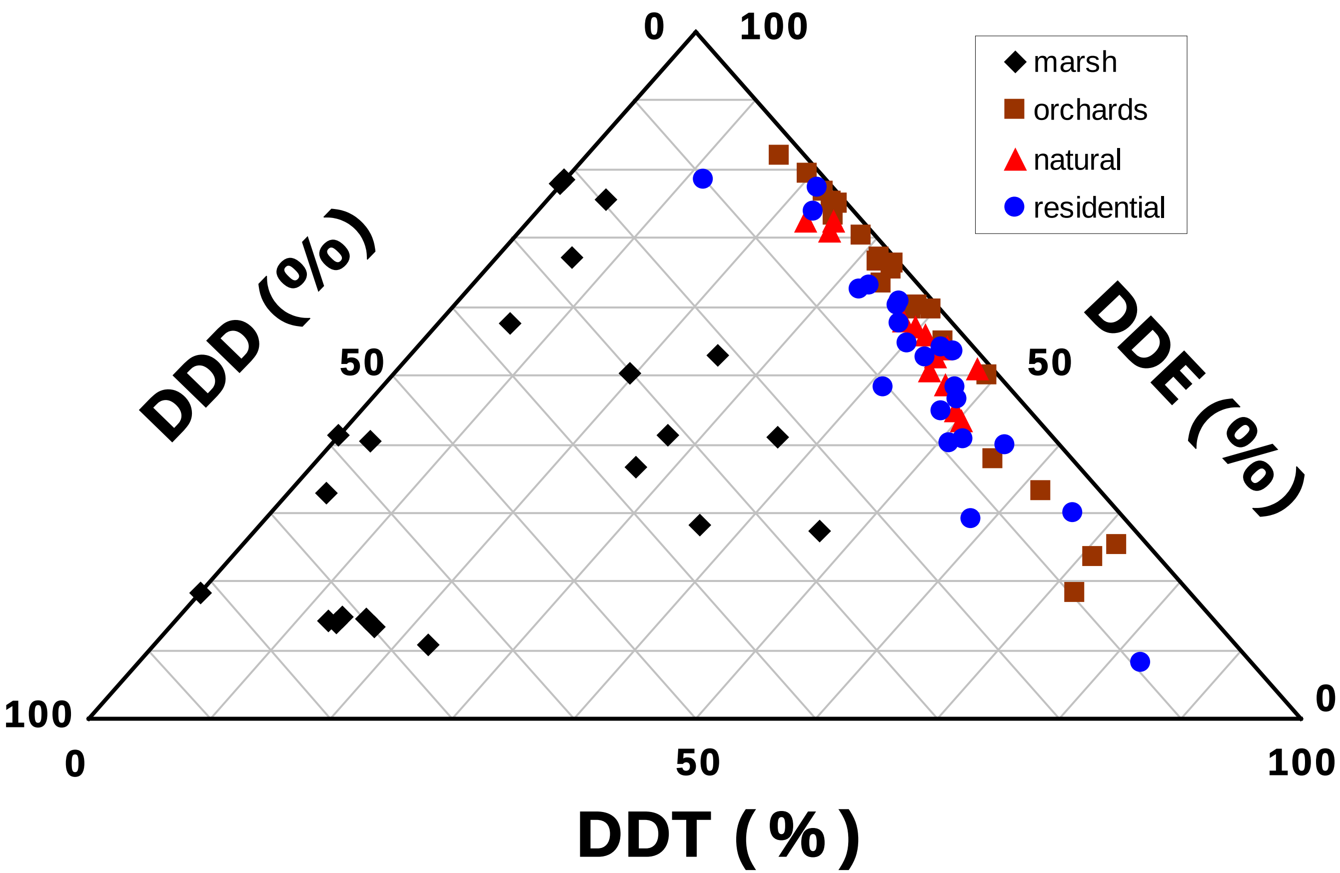
$$X = A + B\cos(60^{o}) \qquad (1)$$

$$Y = A\sin(60^{o}) \qquad (2)$$

A = the first of the three percentage components

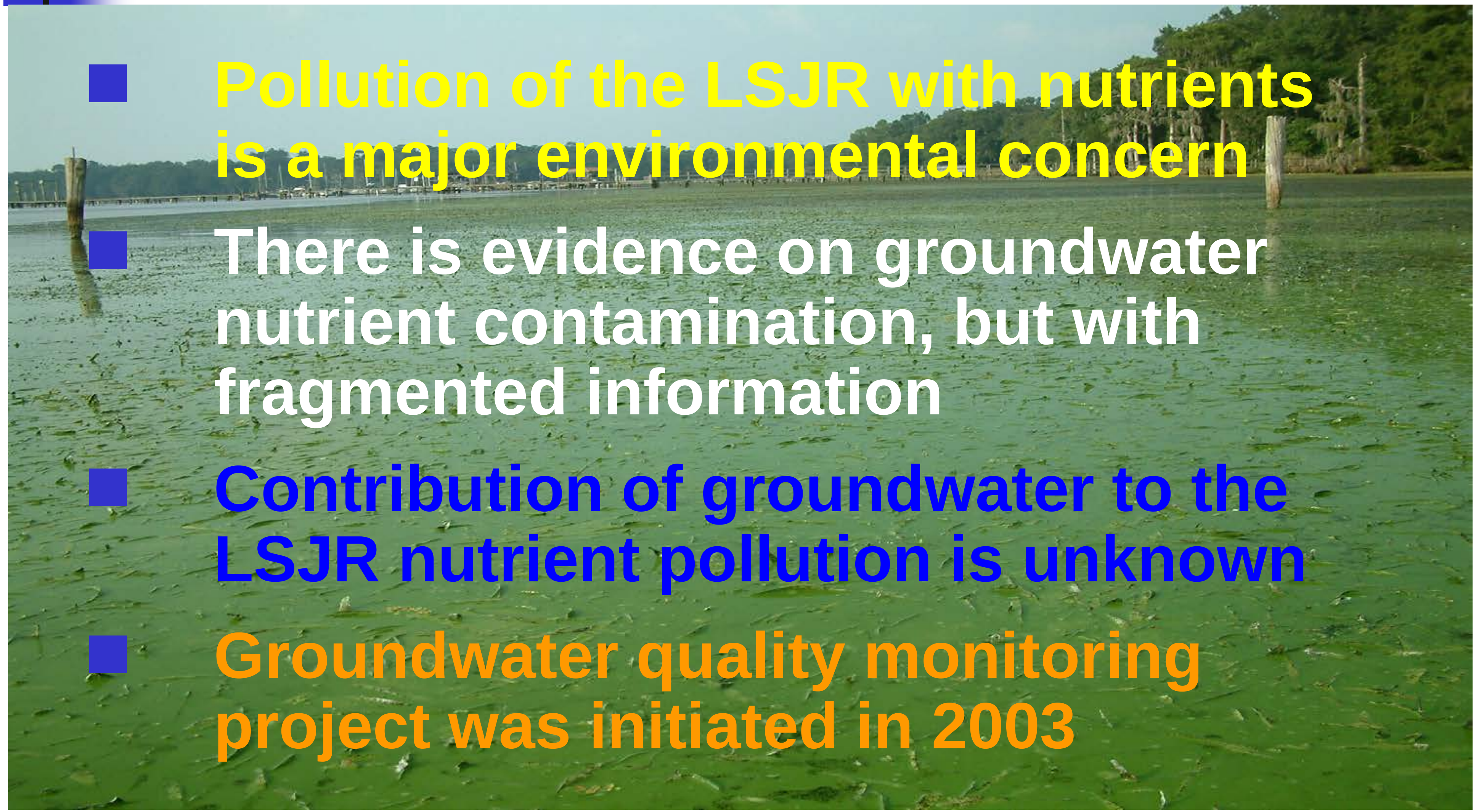
B = the second of the three percentage components

Example of Trilinear Plot



- **Shikaze and Crowe (Ground Water, 2007, 45:106-109)**

Example Application of Trilinear Analysis:
Lower St. Johns River GW Basin

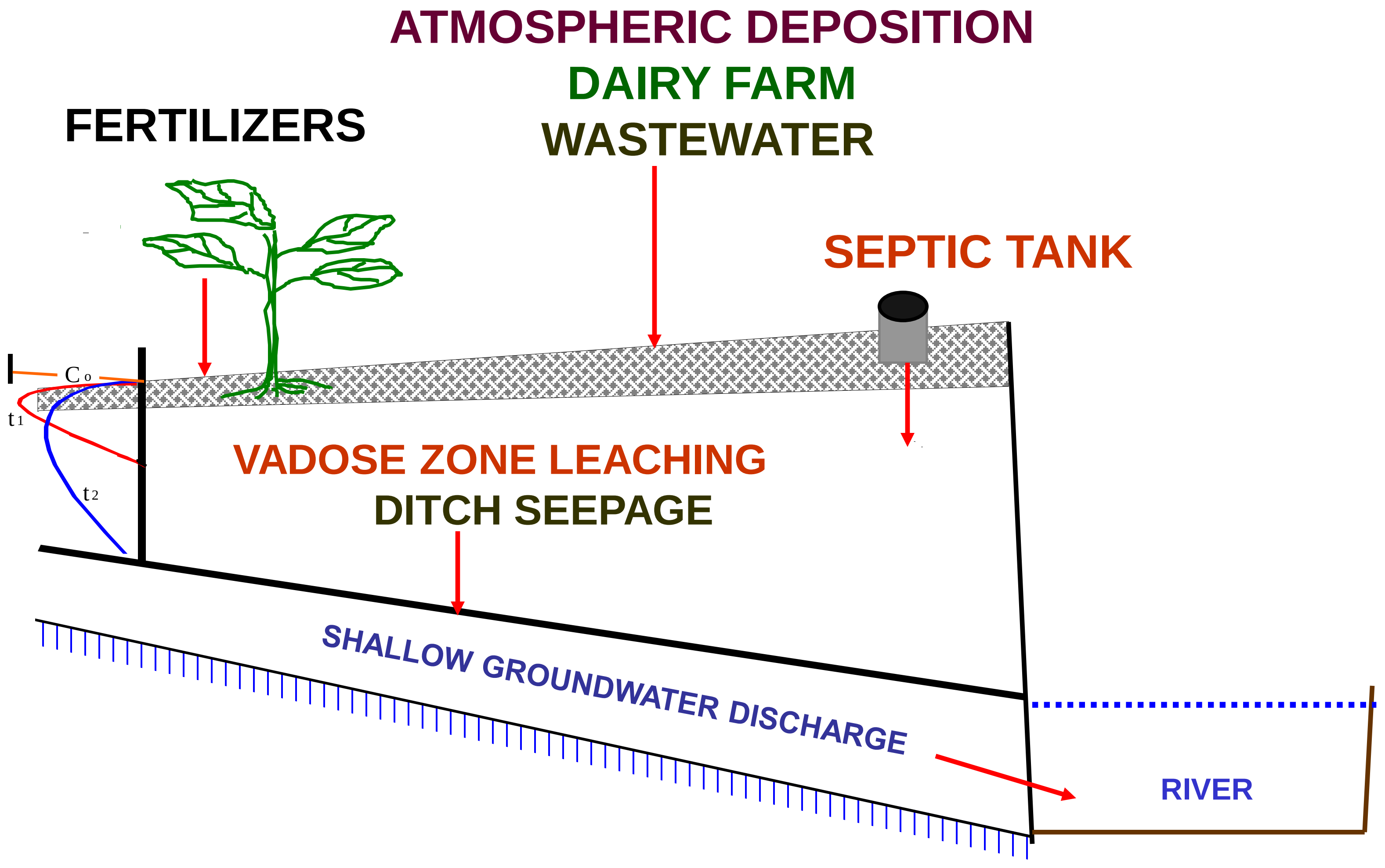


- Pollution of the LSJR with nutrients is a major environmental concern
- There is evidence on groundwater nutrient contamination, but with fragmented information
- Contribution of groundwater to the LSJR nutrient pollution is unknown
- Groundwater quality monitoring project was initiated in 2003

Groundwater Flow and Nutrient Contamination Processes

Sources

Pathways



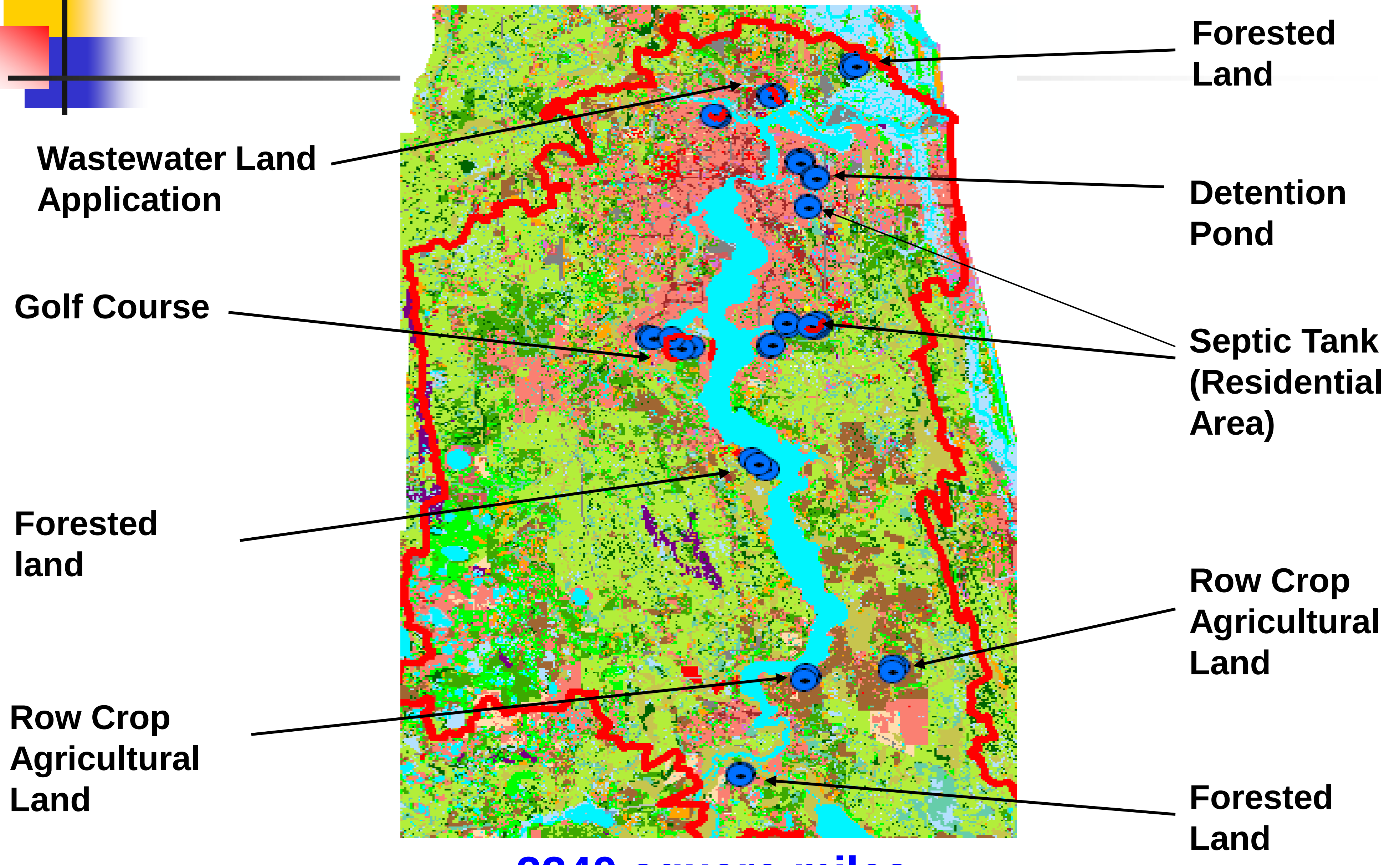
Groundwater Quality Monitoring Project (2003 to 2010)

- Select study sites based on land uses
- Install groundwater monitoring wells
- *In situ* measurement of groundwater levels and some physical parameters
- Collect intensive and seasonal groundwater samples
- Analyze samples at the SJRWMD's Lab

Land Uses and Well Locations

Land Use (4)	Well Location (59 wells)
Natural Forestry	Bayard Point, Clay County Murphys Creek, Putnam County Pumpkin Hill, Duval County
Neighborhoods (Septic Tanks)	Doctors Lake Estates, Clay County Manor Del Rio, Duval County Arlington Manor, Hood landing and Oakwood Villas Areas, Duval County Riverview, Duval County
Agricultural	Yarborough Property, St. Johns County Edgefield Property, St. Johns County
Permitted Land Application of Treated Waste Water	Eagle Harbor, Clay County JEA District II (Tree Farm), Duval County JEA Julington Creek, St. Johns County

Well Location (17 Sites with 59 Wells)



2240 square miles

Groundwater Sampling

Well depth ranges from 5 to 20 ft

Measured Parameters (28)

- Alkalinity
- Ca-T
- Cl
- Conductance
- Sample depth
- DO
- F
- Fe
- Flow Rate-gpm
- Hardness
- K
- Mg
- NaT
- Redox potential
- NH4
- NOx
- pH-Field
- PO4
- SO4
- Sr
- TDS
- TKN
- TP
- TSS
- Turbidity-Field
- Water Level
- Water Temp
- Hydraulic conductivity

Procedures of Trilinear Analysis

A. Partitioning each water quality group into three percentage components as shown below:

1. Total nitrogen (100%): TON% + NO_x% + NH_4%
2. Total phosphorus (100%): PP% + PO_4% + DOP%
3. Major cations (100%): Ca% + Mg% + Na%
4. Major anions (100%): Cl%+ SO_4% + F%
5. Major Heavy metals (100%): As% + Cd% + Cr%

Procedures of Trilinear Analysis

B. Organizing them with land use types (septic tank, forested, wastewater application, and agriculture)

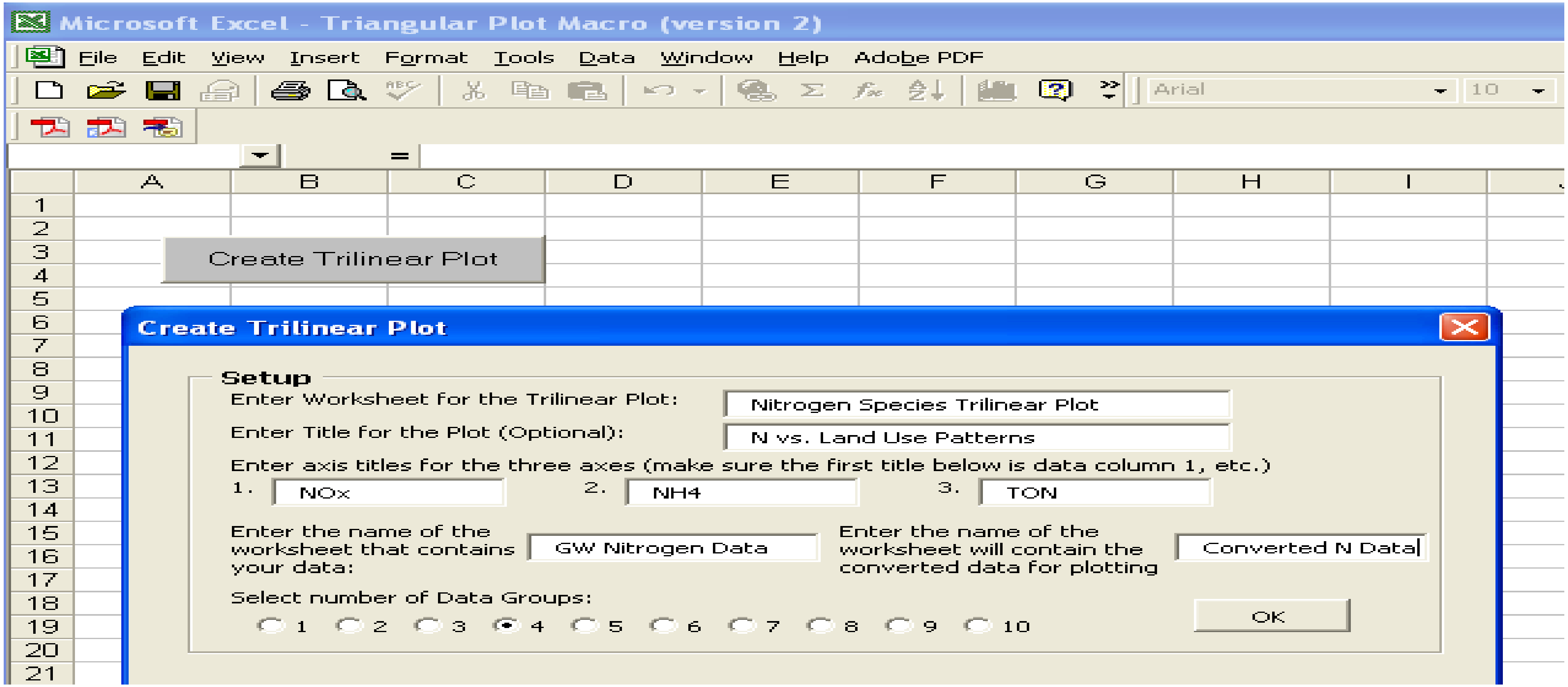
Example for nitrogen

Microsoft Excel - Triangular-N-good2

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Septic Tank	%NO3	%NH4	%TON		Forestry	%NO3	%NH4	%TON		Wastewater	%NO3
3												
4	AM-MW-1	0.40	88.68	10.92		BP-MW-1	6.06	0.00	93.94		EH-MW-1	1.93
5	AM-MW-1	0.46	81.30	18.24		BP-MW-1	5.71	8.10	86.19		EH-MW-1	1.38
6	AM-MW-1	0.58	82.50	16.92		BP-MW-1	3.97	14.06	81.97		EH-MW-1	2.44
7	AM-MW-1	0.26	82.50	17.24		BP-MW-1	10.48	13.00	76.52		EH-MW-1	2.60
8	AM-MW-1	0.50	85.07	14.42		BP-MW-1	11.31	17.87	70.83		EH-MW-1	5.64
9	AM-MW-1	0.29	79.77	19.94		BP-MW-2	12.24	0.00	87.76		EH-MW-2	1.54
10	AM-MW-1	0.28	88.16	11.56		BP-MW-2	3.50	5.68	90.82		EH-MW-2	1.76
11	AM-MW-1	0.30	94.63	5.08		BP-MW-2	21.25	20.81	57.94		EH-MW-2	1.70
12	AM-MW-1	0.15	92.66	7.19		BP-MW-2	6.26	7.26	86.48		EH-MW-2	2.22
13	AM-MW-1	0.24	93.32	6.44		BP-MW-2	2.74	16.07	81.19		EH-MW-2	3.75
14	AM-MW-1	0.63	96.23	3.13		BP-MW-3	1.53	43.05	55.43		EH-MW-3	2.73
15	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]

Procedures of Trilinear Plot

C. Create a trilinear plot using MS Excel (Shikaze and Crowe, 2007)

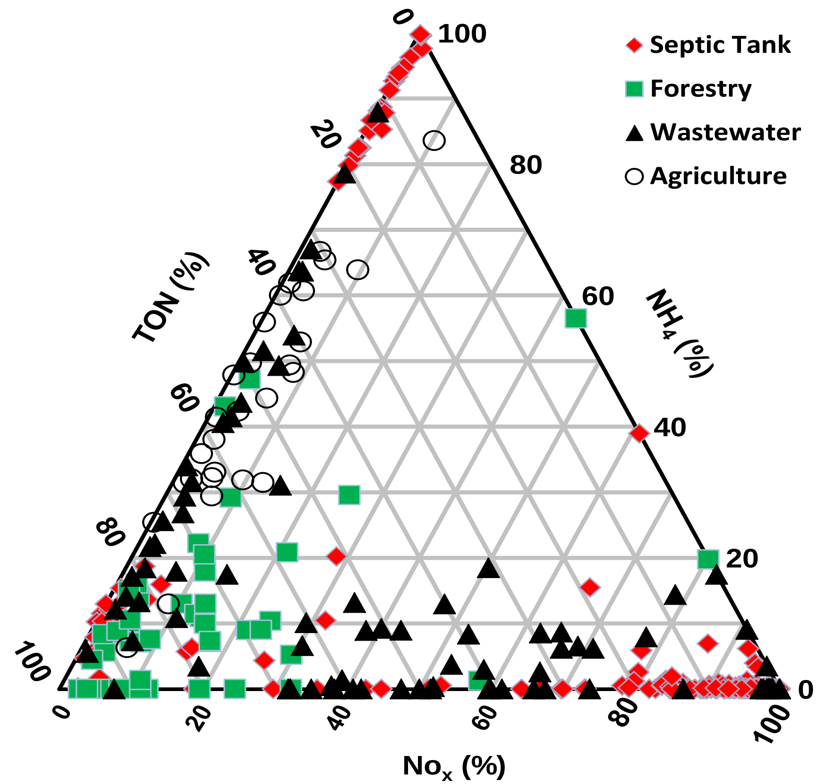


Groundwater N vs. Land Uses

- **Forest land contributed 70-90% of TON in groundwater**
- **Agriculture contributed < 10% of NO_x in groundwater**
- **Septic tank area had two distinct distribution patterns in groundwater:**

  (1) High NO_x and NH_4 (>80%)
  (2) Low TON (< 20%)

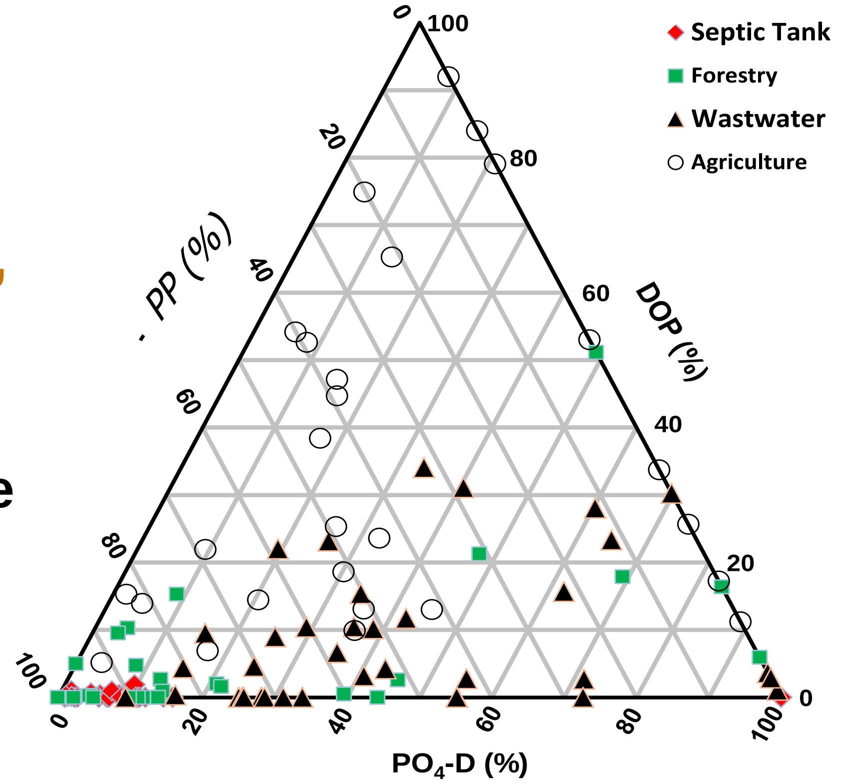
Septic tank leakage of NO_x to groundwater



	Septic Tank			Forestry			Wastewater			Agriculture		
	NOx (mg/L)	NH4 (mg/L)	TON (mg/L)	NOx (mg/L)	NH4 (mg/L)	TON (mg/L)	NOx (mg/L)	NH4 (mg/L)	TON (mg/L)	NOx (mg/L)	NH4 (mg/L)	TON (mg/L)
Mean	7.3768	0.1111	0.2352	0.0159	0.0268	0.2000	1.9224	0.1948	0.2765	0.0407	0.5069	0.5643
Minimum	0.0000	0.0000	0.0000	0.0027	0.0000	0.0000	0.0036	0.0000	0.0000	0.0079	0.0397	0.0526
Maximum	43.7001	3.4704	1.9600	0.0793	0.2064	1.3422	10.5512	3.3131	2.3880	0.1779	1.6537	2.6905

Groundwater P vs. Land Uses

- Forest land contributed 80-100% of PP and 0-20% of DOP and PO4-D in groundwater
- Septic tank area contributed > 90% of PP, < 10% of PO_4-D, and > 5% of DOP in groundwater
- Low percentages of PO_4-D and DOP in the groundwater occurred due to the adsorption and precipitation of these dissolved P species

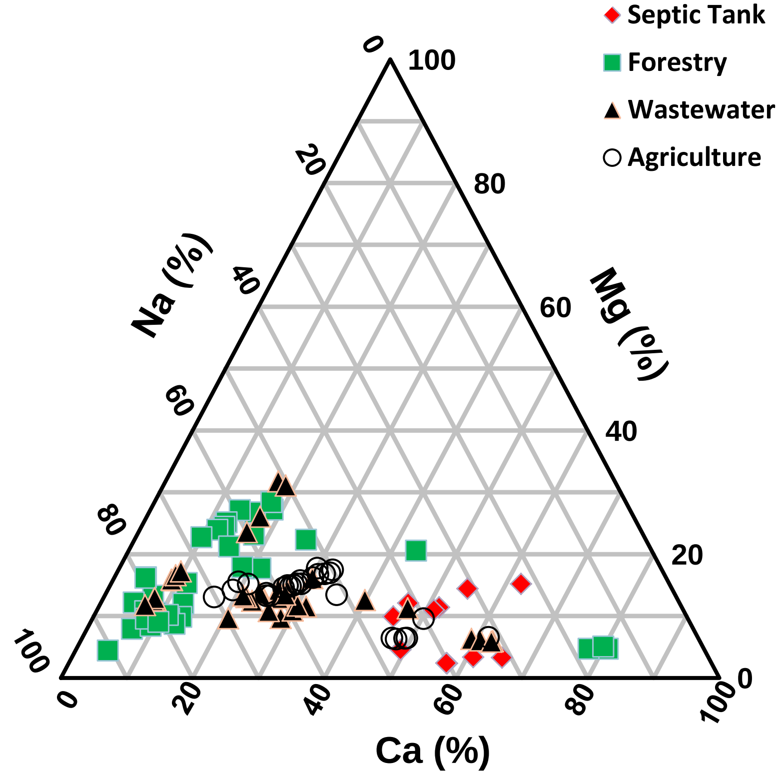


	Septic Tank			Forestry			Wastewater			Agriculture		
	PO4-D (mg/L)	DOP (mg/L)	TP-P (mg/L)	PO4-D (mg/L)	DOP (mg/L)	TP-P (mg/L)	PO4-D (mg/L)	DOP (mg/L)	TP-P (mg/L)	PO4-D (mg/L)	DOP (mg/L)	TP-P (mg/L)
Mean	0.0051	0.0002	0.1065	0.0187	0.0057	0.0541	0.1981	0.0244	0.1094	0.0678	0.1248	0.0549
Minimum	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0084	0.0000	0.0000	0.0015	0.0058	0.0000
Maximum	0.0080	0.0014	0.5557	0.0755	0.0664	0.1606	1.3872	0.1387	0.7149	0.3228	2.0241	0.2285

Groundwater Cations vs. Land Uses

- **Ca was a dominant cation (50-60%) in the groundwater beneath the septic tank lands**

- **Na was a dominant cation (50-90%) in the groundwater beneath the forest lands**

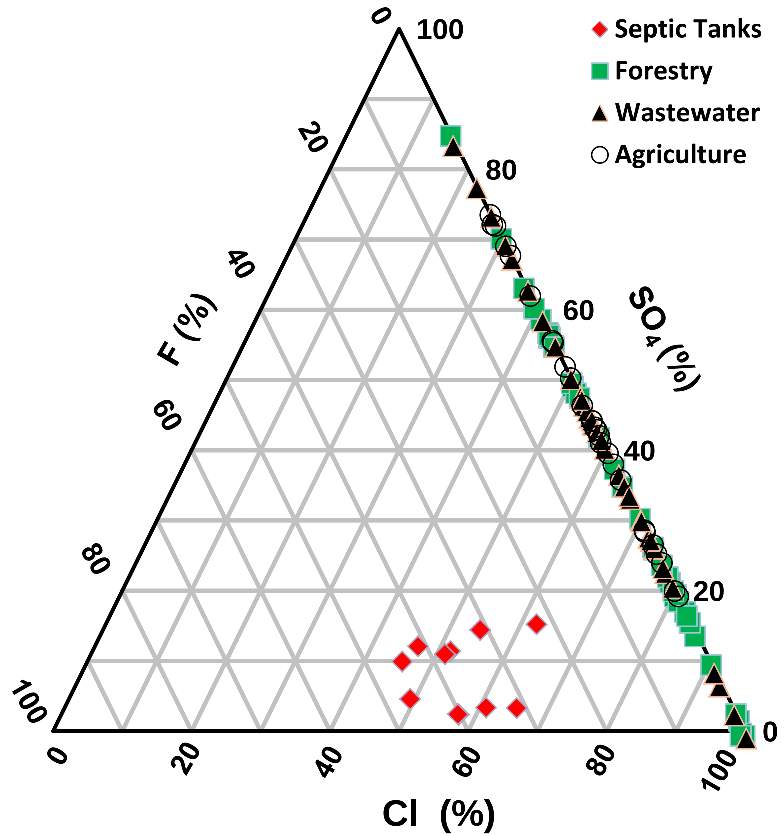


	Septic Tank			Forestry			Wastewater			Agriculture		
	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)
Mean	34.4602	3.6327	23.1910	6.4091	1.4933	6.3671	27.6628	11.6787	52.8741	85.8738	40.7408	148.7827
Minimum	7.9918	1.7383	7.8179	0.3890	0.3470	1.8460	0.7406	1.2050	6.3620	23.6488	7.4020	36.1580
Maximum	67.6880	6.8063	47.2990	74.5460	4.7340	14.7690	65.3340	31.3230	132.0350	263.1010	154.7610	456.3350

Groundwater Anions vs. Land Uses

- F accounted for < 1% of the total anions in the groundwater beneath the forest, wastewater, and agricultural lands

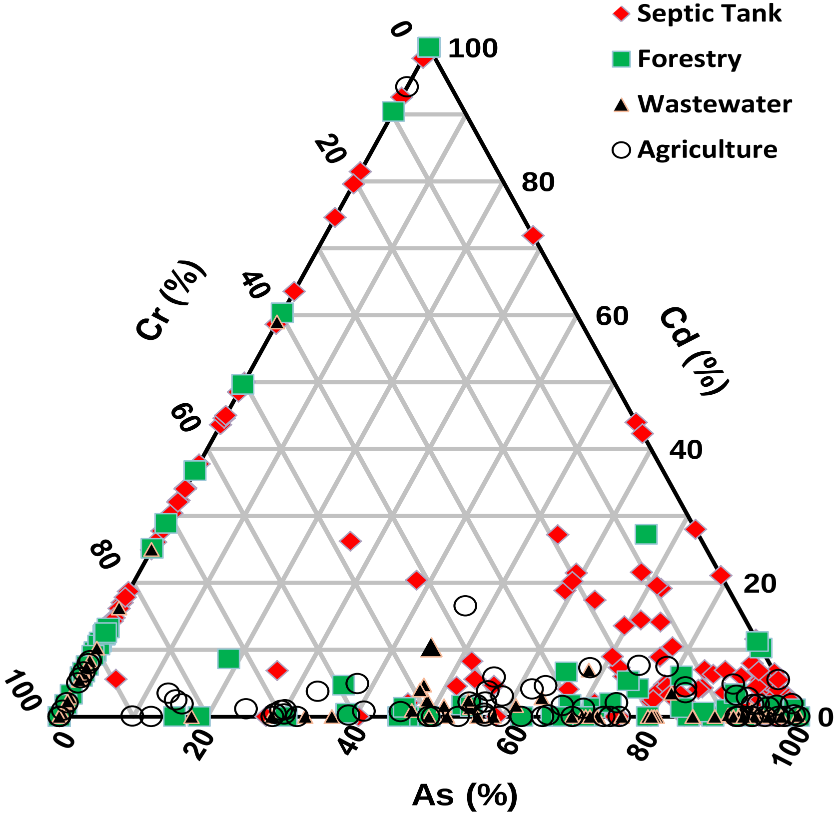
- There was a relatively high percentage of F and Cl in the groundwater beneath the septic tank land due to the high F content in the tap water



	Septic Tank			Forestry			Wastewater			Agriculture		
	Cl (mg/L)	SO4 (mg/L)	F (mg/L)	Cl (mg/L)	SO4 (mg/L)	F (mg/L)	Cl (mg/L)	SO4 (mg/L)	F (mg/L)	Cl (mg/L)	SO4 (mg/L)	F (mg/L)
Mean	36.50588	58.775278	0.054057	11.585951	6.405663	0.047471	84.0961504	65.106865	0.138721	318.79048	233.1193	0.473566
Minimum	7.871853	19.95	0.0153	2.7082484	0	0.005	1.19	0	0.005	44.428352	19.4	0.091904
Maximum	94.4	108.69966	0.1122	21.156	27.3	0.1511	199.996	235.0668	0.537489	1022.6265	808.2459	2.6316

Heavy Metals vs. Land Uses

- Arsenic had relatively high percentages among the three major heavy metals from the wastewater and agricultural lands



	Septic Tank			Forestry			Wastewater			Agriculture		
	As (μg/L)	Cd (μg/L)	Cr (μg/L)	As (μg/L)	Cd (μg/L)	Cr (μg/L)	As (μg/L)	Cd (μg/L)	Cr (μg/L)	As (μg/L)	Cd (μg/L)	Cr (μg/L)
Mean	1.312422	0.0522681	0.234084	0.6375107	0.046016	0.72186	5.55551493	0.0314812	1.212952	4.269674	0.09817	2.955282
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	24.39	0.5321	2.846	4.103	0.404738	8.435	34	0.256	4.775	40.6	0.6223	72.36

Summary

- Application of trilinear analysis
- Impacts of land use upon groundwater quality
- Forest land accounted for more TON and PP in the shallow groundwater
- Septic tank area contributed more NO_x and F in shallow groundwater
- Trilinear analysis is a useful tool to identify relationship between water quality and land use